APPLICATION

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PATENT

BIDIRECTIONAL OPTICAL INTERLEAVER

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BIDIRECTIONAL OPTICAL INTERLEAVER

BACKGROUND OF THE INVENTION

[0001] This invention relates to optical communication systems, and more particularly, to a bidirectional optical interleaver.

[0002] Demand for voice and data bandwidth in telecommunications networks continues to increase as population grows, work habits evolve (for example, the increased reliance on telecommuting and video/teleconferencing) and business and personal usage of internet-based telecommunications accelerates. Network operators and telecommunications service providers face an increasingly competitive environment that demands low operating and infrastructure costs, and fast supply of new capacity. Operators and service providers are thus motivated to deploy optical telecommunications equipment that maximizes feature and function density within their facilities.

[0003] The telecommunications industry has been actively working to develop new technologies to increase network capacity while continuing to meet the financial expectations experienced in today's less regulated telecommunication landscape. Of particular importance has been the emergence of wavelength division multiplexing ("WDM"), which supports the transmission of multiple optical channels (each channel having a different wavelength) on a single fiber. Each channel is modulated with a different information signal to thus provide a substantial increase in data and voice carrying capacity without requiring the installation of new transport media, such as optical cables, in the network.

[0004] Dense wavelength division multiplexing ("DWDM") technology is developing as an approach to scale up network capacity even further. In DWDM technology, the

optical channels are packed more tightly within the available transmission spectrum. Individual optical channels thus become more closely spaced. Recently, 400 and 200 GHz spacings were common for optical channels. As the state of the art improved, 100 GHz and then 50 GHz channel spacing has become more common. Optical interleaving products have been introduced to address capacity needs by interleaving multiple sets of optical channels into a more densely packed stream. In its simplest form, with 2 x 1 interleaving, two subsets of optical channels are multiplexed into a single set with half the channel spacing of the subsets. A 1 x 2 deinterleaver operates in a complementary manner to demultiplex a set of optical channels into two subsets of optical channels where each subset has twice the channel spacing of the input set. The single term "interleaver" is typically used to refer to both multiplexing and demultiplexing functions. Currently, interleavers may be used to support either multiplexing or demultiplexing, but not both functions simultaneously.

[0005] Interleavers are utilized in transmission applications include multiplexing (and demultiplexing) in DWDM networks. Optical Add/Drop Multiplexing ("OADM") is another common application. In addition, interleavers may be deployed as an interface among transmission streams having unequal channel spacings to allow existing networks to be gracefully scaled upwards to meet future capacity demands. While current interleaver technology is entirely satisfactory in many applications, some classes of interleavers are physically large while others may be complex to manufacture and thus have high costs. Accordingly, it would be very desirable to reduce size and costs while increasing the feature set and functionalities provided in today's optical networking infrastructure.

SUMMARY OF THE INVENTION

[0006] An inventive method and apparatus is provided by a bidirectional optical 1 x 2 device formed by a cascade of three optical 2 x 2 devices. The first of two distal end ports of a first 2 x 2 device in the first tier of the cascade is optically coupled via a first bidirectional optical path to a proximal end port of a second 2 x 2 device (one of two 2 x 2 devices in the second tier of the cascade). The second distal end port of the first 2 x 2 device is optically coupled via a second bidirectional optical path to a proximal end port of the third 2 x 2 device (the other of the two 2 x 2 devices in the second tier of the cascade).

[0007] Each 2 x 2 device is bidirectional where optical signals propagate through the 2 x 2 device in the forward and backward directions simultaneously. An input WDM signal is received at a first proximal end port of the first 2 x 2 device. As the input WDM signal forward propagates through the first 2 x 2 device (from proximal end to distal end), it is demultiplexed into first and second subsets of optical channels. In some applications of the invention, the channel spacing in each of the first and second subsets may be approximately double that of the input WDM signal.

[0008] Third and fourth subsets of optical channels are received, respectively, at a distal end port of the second 2 x 2 device and a distal end port of the third 2 x 2 device. As the third and fourth subsets of optical channels backward propagate through the first 2 x 2 device (from distal end to proximal end), they are multiplexed into an output WDM signal that is output at the second proximal end port of the first 2 x 2 device. In some applications of the invention, the output WDM signal may have a channel spacing that is approximately half that of the third and fourth subsets. The demultiplexing in the forward direction and multiplexing in the backward direction occur simultaneously to thereby

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perform bidirectional 1 x 2 optical demultiplexing and 2 x 1 optical multiplexing in the 1 x 2 device.

[0009]   In illustrative embodiments of the invention, a bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer is disclosed for demultiplexing an input WDM signal propagating in the forward direction into four discrete output channels while simultaneously multiplexing four discrete input channels propagating in the backward direction into an output WDM signal. The bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer is arranged from a two-tiered cascade of three 1 x 2 devices. The input WDM signal is received at the proximal end of the cascade and the four discrete input channels are received at the distal end. A bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer is also disclosed for demultiplexing an input WDM signal propagating in the forward direction into a eight discrete output channels while simultaneously multiplexing eight discrete input channels propagating in the backward direction into an output WDM signal. The bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer is arranged from a three-tiered cascade of seven 1 x 2 devices. Optical isolators are disposed at each input of the cascade in both the four and eight channel embodiments (i.e., at the proximal end input for the WDM signal and at each of the distal end inputs for the discrete input channels) to prevent feedback to the signal sources.

[0010]   In another illustrative embodiment of the invention, an input WDM signal having N channels is received at a first proximal end port of a 1 x 2 device disposed in a first tier of a cascade of (N-1) 1 x 2 devices having m tiers where $2^m = N$. As the input WDM signal forward propagates through the cascade, 1 x N demultiplexing thereby occurs to generate a set of N discrete output channels that are output at respective first distal end ports of the 2 x 2 devices in the last tier (i.e., the mth tier) of the cascade.

[0011]   A set of N discrete input channels is received at second distal end ports of the 2 x 2 devices in the mth tier of the cascade. As the set of N input channels backward propagates through the cascaded array, N x 1 optical multiplexing thereby occurs to generate an output WDM signal that is output at a second proximal end port of the 1 x 2 optical device in the 1st tier of the cascade. Optical isolators are disposed at the inputs of the cascade (i.e., at the proximal end input for the WDM signal and at each of the N distal end inputs) to prevent feedback to the signal sources.

[0012]   Advantageously, the invention provides simultaneous multiplexing and demultiplexing through a single optical cascade. By functioning bidirectionally, the invention doubles the feature set while maintaining the same footprint as single function equipment. In addition, the doubled functionality does not come at twice the cost of single function equipment as only incremental costs are incurred to implement the invention.

BRIEF DESCRIPTION OF THE DRAWING

[0013]   FIG 1 depicts a bidirectional 1 x 2 device comprising three cascaded 2 x 2 devices arranged in accordance with the invention;

[0014]   FIG 2 depicts a bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer that is arranged from three cascaded bidirectional 1 x 2 devices, in accordance with the invention; and

[0015]   FIG 3 depicts a bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer that is arranged from a plurality of cascaded bidirectional 1 x 2 devices, in accordance with the invention.

DETAILED DESCRIPTION

[0016]   Referring now to FIG 1, a bidirectional 1 x 2 optical device 100 is depicted. As used here, the nomenclature "1 x 2" is used to indicate that an input signal is demultiplexed into two signals in the forward direction, and two input signals are multiplexed into a single output signal in the backward direction. As indicated in FIG 1, the forward direction of signal propagation is oriented from left to right on the page, while the backward direction is oriented from right to left.

[0017]   The bidirectional 1 x 2 devices is comprised of three 2 x 2 devices 110_1, 110_2, and 110_3. As used here, "2 x 2" device means a device having four optical ports where two optical ports are located at the proximal end of the device, and the remaining two optical ports are located at the distal end of the device. In all the figures accompanying this description, the proximal end of a device is located on its left side, while the distal end is located on its right. Signals propagate in the forward direction in devices from proximal end to distal end, and backward propagate from distal end to proximal end. It is noted that the term "signal" is used generally to refer to an information stream propagated within an optical medium (including optical paths and devices) and may include one or more optical channels.

[0018]   Each 2 x 2 device 110 may be selected from a variety of optical devices including couplers, narrow band couplers, Mach-Zehnder interferometers, interleavers, and Fourier filters. As shown in FIG 1, the 2 x 2 devices 110 are arranged in cascade having two tiers. The 2 x 2 device 110_1 is located in the first tier of the cascade and 2 x 2 optical devices 110_2 and 110_3 are located in the second tier. The 2 x 2 device 110_1 in the first tier of the cascade is optically coupled to both 2 x 2 devices 110_2 and 110_3 in the second tier. As shown, bidirectional optical path 155, which may comprise an optical

fiber, optically couples one of the two distal end ports of 2 x 2 device 110_1 to one of the proximal end ports of 2 x 2 device 110_2. Similarly, bidirectional optical path 165, which may comprise an optical fiber, optically couples the other distal end port of 2 x 2 device 110_1 to one of the proximal end ports of 2 x 2 device 110_3.

[0019]   Unidirectional optical path 142 is coupled to one of the proximal end ports of 2 x 2 device 110_1. Unidirectional optical path 147 is coupled to the other proximal end port of 2 x 2 device 110_1. Unidirectional optical path 142 is configured to carry an input WDM signal as an input to the 2 x 2 device 110_1 (and accordingly, to the 1 x 2 device 100). Unidirectional optical path 147 is configured to carry an output WDM signal as an output from the 2 x 2 device 110_1 (and accordingly, from the 1 x 2 device 100).

[0020]   At the distal ends of 2 x 2 devices 110_2 and 110_3, unidirectional optical fibers 170, 173, 182 and 185 are coupled to the four respective distal end ports, as shown in FIG 1. Unidirectional optical fibers 170, 173, 182 and 185 may comprise optical fibers. Unidirectional optical path 170 is configured to carry an optical signal as an output from the first distal end ports of 2 x 2 device 110_2. Unidirectional path 173 is configured to carry an optical signal as an input to the second distal end port of 2 x 2 device 110_2. Unidirectional optical path 182 is configured to carry an optical signal as an input from the first distal end ports of 2 x 2 device 110_3. Unidirectional path 185 is configured to carry an optical signal as an output from the second distal end port of 2 x 2 device 110_3.

[0021]   The arrangement of the optical paths 142, 147, 170, 173, 182 and 185 thus configures 1 x 2 device 100 so that an input WDM signal received at the proximal end of the cascade (at optical path 142) is demultiplexed (via forward propagation through the device as indicated by arrow 112 in FIG 1) into two output signals at the distal end of the cascade (at optical paths 170 and 185). In addition, two signals input at the distal end of

the cascade (at optical paths 173 and 182) are multiplexed (as indicated by the arrow 114 in FIG 1) into a single output WDM signal that is output at the proximal end of 1 x 2 device 100 (at optical path 147). In accordance with the invention, 1 x 2 device 100 thus simultaneously operates as a 1 x 2 demultiplexer in the forward direction and a 2 x 1 multiplexer in the backward direction by using bidirectional signal propagation.

[0022]   In the illustrative embodiment shown in FIG 1, an input WDM signal having four optical channels – $\lambda 1F$, $\lambda 2F$, $\lambda 3F$, and $\lambda 4F$ – is received on optical path 142 at the first proximal end port of 2 x 2 device 110_1 in the first tier of the cascade. The designation "F" indicates that these optical channels forward propagate through the cascade forming the 1 x 2 device 100. The four channels of the input WDM signal in this embodiment is merely illustrative as other channel counts may also be utilized in the invention. For example, in the case of an eight channel input WDM signal, in the forward direction, the 1 x 2 device 100 demultiplexes the input WDM signal into two output signals having four channels each.

[0023]   As the input WDM signal forward propagates through 2 x 2 device 110_1, it is demultiplexed into first and second subsets of optical channels. The first subset of optical channels, including $\lambda 1F$ and $\lambda 3F$, is output at the first distal end port of 2 x 2 device 110_1, and is carried in the forward direction by bidirectional optical path 155 to a proximal end port of 2 x 2 device 110_2. The second subset, including $\lambda 2F$ and $\lambda 4F$, is output at the second distal end port of 2 x 2 device 110_1, and is carried in the forward direction by bidirectional optical path 165 to a proximal end port of 2 x 2 device 110_3. The first subset, including $\lambda 1F$ and $\lambda 3F$, forward propagates through 2 x 2 device 110_2, and is output on the first distal end port of device 110_2 on unidirectional optical path 170 at the distal end of the cascade, as shown in FIG 1. Similarly, the second subset, including $\lambda 2F$ and $\lambda 4F$,

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forward propagates through 2 x 2 device 110_3, and is output on the second distal end port of 2 x 2 device 110_3 on unidirectional optical path 185 at the distal end of the cascade.

[0024]   As depicted in FIG 1, the even-numbered channels of the input WDM signal are output on one optical path exiting the 1 x 2 device 100 (path 170) and the odd channels are output on another optical path exiting the 1 x 2 device 100 (path 185). In some applications of the invention, the channel spacing of the output signal may be arranged to be approximately twice the channel spacing of the input WDM signal. In accordance with the invention, therefore, the separation of the channels making up the input WDM signal into odd and even subsets each having increased channel spacing may be advantageously used to deinterleave the input WDM signal.

[0025]   At the distal end of the 1 x 2 device 100, input signals are received at one of the two distal end ports of each 2 x 2 devices 110_2 and 110_3 in the second tier of the cascade. As shown in FIG 1, a third subset of optical channels, including $\lambda 2B$ and $\lambda 4B$, is received at the second distal end port of 2 x 2 device 110_2 on unidirectional optical path 173. Similarly a fourth subset of optical channels, including $\lambda 1B$ and $\lambda 3B$, is received at the first distal end port of 2 x 2 device 110_3 on unidirectional optical path 182. The designation "B" indicates that these optical channels backward propagate through the cascade forming the 1 x 2 device 100.

[0026]   In accordance with the invention, $\lambda 1F$, $\lambda 2F$, $\lambda 3F$ and $\lambda 4F$ may be substantially equal in wavelength to $\lambda 1F$, $\lambda 2B$, $\lambda 3B$, and $\lambda 4B$, respectively, and vary only in terms of direction of propagation through the 1 x 2 device 100. However, such substantial equality is not a requirement imposed by the invention. The two channels in each of the third and fourth subsets in this embodiment are merely illustrative as other channels counts may be utilized in the invention. For example, in the case of the third and fourth subsets having

four channels each, in the backward direction, the 1 x 2 device 100 multiplexes the third

and fourth subsets into an output WDM signal having eight channels.

[0027] The third subset of optical channels received on unidirectional optical path

173 backward propagates through 2 x 2 device 110_2, is output on the proximal end port,

and is carried by the bidirectional optical path 155 to the first distal end port of 2 x 2

device 110_1. Similarly, the fourth subset of optical channels received on optical path 182

backward propagates through 2 x 2 device 110_3, is output on the proximal end port, and is

carried by the bidirectional optical path 165 to the second distal end port of 2 x 2 device

110_1. In accordance with the invention, bidirectional optical path 155 is configured so that

it may simultaneously carry the forward propagating optical channels $\lambda 1F$ and $\lambda 3F$, and

backward propagating channels $\lambda 2B$ and $\lambda 4B$. Similarly, bidirectional optical path 165 is

configured so that it may simultaneously carry the forward propagating optical channels

$\lambda 2F$ and $\lambda 4F$, and backward propagating channels $\lambda 1B$ and $\lambda 3B$.

[0028] The third and fourth subsets of optical channels are multiplexed as they

backward propagate through 2 x 2 device 110_1. The multiplexed optical channels are

output as an output WDM signal on the second proximal end port of 2 x 2 device 110_1 on

unidirectional optical path 147. As depicted in FIG 1, the output WDM signal comprises

$\lambda 1B$, $\lambda 2B$, $\lambda 3B$ and $\lambda 4B$. In some applications of the invention, the channel spacing of the

output WDM signal may be arranged to be approximately half that of the first and second

subsets of optical channels. In accordance with the invention, therefore, the 1 x 2 device

100 shown in FIG 1 may be advantageously used as an interleaver. Such interleaving may

be performed simultaneously with the deinterleaving function described above.

[0029] Referring now to FIG 2, an illustrative bidirectional 1 x 4 demultiplexer, 4 x 1

multiplexer 200 is depicted that is arranged from three cascaded 1 x 2 devices, in

accordance with the invention. The nomenclature "1 x 4" and "4 x 1" is used to indicate, respectively, the demultiplexing of an input WDM signal into four discrete output signals in the forward direction, and the multiplexing of four discrete input signals into a single output WDM signal in the backward direction.

[0030] In accordance with the invention, the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200 demultiplexes an input WDM signal received at the proximal end of the cascade into four discrete optical channels at the distal end. As indicated by the arrow 212 in FIG 2, the demultiplexing occurs as the input WDM signal forward propagates through the two tiered cascade forming the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200. In addition, as indicated by the arrow 214 in FIG 2, four discrete channels received at the distal end of the cascade are multiplexed as the channels backward propagate through the two tiered cascade forming the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200. In accordance with the invention, the demultiplexing and multiplexing functions is performed simultaneously using bidirectional optical signal propagation.

[0031] The 1 x 2 devices, identified by reference numerals $202_{1, 2, 3}$ in FIG 2, are each similar in form and operation to the 1 x 2 device 100 shown in FIG 1 and described in the accompanying text. The cascade is arranged in two tiers where the first tier (designated as m = 1 in FIG 2) comprises a 1 x 2 device 202_1 that is optically coupled to both the 1 x 2 device 202_2 and the 1 x 2 device 202_3 that are each disposed in the second tier (designated as m = 2 in FIG 2).

[0032] As shown in FIG 2, 2 x 2 device 210_2 in 1 x 2 device 202_1 is coupled at the first distal end port via unidirectional optical path 221 to a first proximal end port of 2 x 2 device 224_1 in 1 x 2 device 202_2. The second proximal end port of 2 x 2 device 224_1 is coupled via unidirectional optical path 219 to the first distal end port of 2 x 2 device 210_3

in 1 x 2 device 202_1. The second distal end port of 2 x 2 device 210_3 is coupled via unidirectional optical path 231 to the second proximal end port of 2 x 2 device 235_1 in 1 x 2 device 202_3. The first proximal end port of 2 x 2 device 235_1 is coupled via unidirectional optical path 217 to the second distal end port of 2 x 2 device 210_2 in 1 x 2 device 202_1. Optical paths 221, 219, 231, and 217 may comprise optical fibers.

[0033]   In the illustrative embodiment shown in FIG 2, an input WDM signal having four optical channels – $\lambda 1F$, $\lambda 2F$, $\lambda 3F$, and $\lambda 4F$ – is received on unidirectional optical path 201 at the first proximal end port of 2 x 2 device 210_1 in the 1 x 2 device 202_1 in the first tier of the cascade. An optical isolator 205_1 is disposed along the optical path 201 to prevent feedback to the WDM signal source (not shown in FIG 2).

[0034]   As the input WDM signal forward propagates through 2 x 2 device 210_1, it is demultiplexed into first and second subsets of optical channels. The first subset of optical channels, $\lambda 1F$ and $\lambda 3F$, is carried in the forward direction by bidirectional optical path 212. The second subset, including $\lambda 2F$ and $\lambda 4F$, is carried in the forward direction by bidirectional optical path 214. The first subset, including $\lambda 1F$ and $\lambda 3F$, forward propagates through 2 x 2 device 210_2, and is output on the first distal end port of device 210_2 on unidirectional optical path 221 in the forward direction to the first proximal end port of 2 x 2 device 224_1 in the 1 x 2 device 202_2. Similarly, the second subset, including $\lambda 2F$ and $\lambda 4F$, forward propagates through 2 x 2 device 210_3, and is output on the first distal end port of 2 x 2 device 210_3 on unidirectional optical path 231 in the forward direction to the second proximal end port of 2 x 2 device 235_1 in 1 x 2 device 202_3. In accordance with the invention, the even-numbered channels of the input WDM signal are output on unidirectional optical path 231 and the odd channels are output on unidirectional optical path 221. In some applications of the invention, the channel spacing

of the signals output on unidirectional optical paths 231 and 221 may be arranged to be approximately twice the channel spacing of the input WDM signal received on unidirectional optical path 201.

[0035]   The first subset of optical channels, including λ1F and λ3F, forward propagates through 2 x 2 device 224_1 where it is demultiplexed so that a single optical channel λ1F is carried in the forward direction by bidirectional optical path 223 to a proximal end port of 2 x 2 device 224_2, and a single optical channel λ3F is carried in the forward direction by bidirectional optical path 222 to a proximal end port of 2 x 2 device 224_3. The optical channel λ1F forward propagates through 2 x 2 device 224_2 and is output on the first distal end port to unidirectional optical path 226. The optical channel λ3F forward propagates through 2 x 2 device 224_3 and is output at the first distal end port to unidirectional optical path 228.

[0036]   The second subset of optical channels, including λ2F and λ4F, forward propagates through 2 x 2 device 235_1 where it is demultiplexed so that a single optical channel λ2F is carried in the forward direction by bidirectional optical path 233 to a proximal end port of 2 x 2 device 235_2 and a single optical channel λ4F is carried in the forward direction by bidirectional optical path 232 to a proximal end port of 2 x 2 device 235_3. The optical channel λ2F forward propagates through 2 x 2 device 235_2 and is output on the first distal end port on unidirectional optical path 236. The optical channel λ4F forward propagates through 2 x 2 device 235_3 and is output at the first distal end port on unidirectional optical path 238.

[0037]   Therefore in the forward direction, in accordance with the invention, as the input WDM signal having four channels (λ1F, λ2F, λ3F, and λ4F) forward propagates

through the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200, it is demultiplexed and the four optical channels emerge as discrete channels on respective optical paths 226, 228, 236, and 238 at the distal end. In the first tier of the cascade (i.e., 1 x 2 device 202_1), the input WDM signal is demultiplexed into separate odd and even optical channel subsets. In this illustrative example, each subset contains two optical channels. The odd and even optical channels subsets are demultiplexed in respective 1 x 2 devices in the second tier of the cascade to further demultiplex each optical channel subset by half again and output each subset half at the distal end of the second tier. Of course in this illustrative example, by splitting each subset of two members in half, the second tier operates to create discrete optical output channels. In some applications of the invention, the channel spacing may thus be approximately doubled as the input WDM signal is demultiplexed as it forward propagates from the first tier to the second tier in the cascade forming the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200.

[0038]   In the illustrative embodiment shown in FIG 2, four discrete optical channels – $\lambda3B$, $\lambda1B$, $\lambda4B$, and $\lambda2B$ – are received on respective unidirectional optical paths 227, 229, 237 and 239 at respective second distal end ports of 2 x 2 devices 224_2, 224_3, 235_2 and 225_3. Optical isolators 205_2, 205_3, 205_4 and 205_5 are disposed along the optical paths, as shown, to prevent feedback to the optical channel sources (not shown in FIG 2). In accordance with the invention, $\lambda1F$, $\lambda2F$, $\lambda3F$ and $\lambda4F$ may be substantially equal in wavelength to $\lambda1B$, $\lambda2B$, $\lambda3B$, and $\lambda4B$, respectively, and vary only in terms of direction of propagation through the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200. However, such substantial equality is not a requirement imposed by the invention.

[0039]   At 1 x 2 device 202_2, $\lambda3B$ and $\lambda1B$ are received at respective second distal end ports of 2 x 2 device 224_2 and 224_3. $\lambda3B$ backward propagates through 2 x 2 device 224_2,

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is output on a proximal end port of device 224_2, and is carried by optical path 223 in the backward direction to the first distal end port of 2 x 2 device 224_1. Similarly, optical channel $\lambda 1B$ backward propagates through 2 x 2 device 224_3, is output on a proximal end port of 2 x 2 device 224_3, and is carried by optical path 222 in the backward direction to the second distal end port of 2 x 2 device 224_1. As they backward propagate, 2 x 2 device 224_1 multiplexes $\lambda 3B$ and $\lambda 1B$ into a third subset of optical channels that is output on the second proximal end port of 2 x 2 device 224_1 and carried by optical path 219 in the backward direction to the first distal end port of 2 x 2 device 210_3 in the 1 x 2 optical device 202_1.

[0040]   At 1 x 2 device 202_3, $\lambda 4B$ and $\lambda 2B$ are received at respective second distal end ports of 2 x 2 device 225_2 and 225_3. $\lambda 4B$ backward propagates through 2 x 2 device 225_2, is output on a proximal end port of device 235_2, and is carried by optical path 217 in the backward direction to the first distal end port of 2 x 2 device 235_1. Similarly, optical channel $\lambda 2B$ backward propagates through 2 x 2 device 235_3, is output on a proximal end port of 2 x 2 device 235_3, and is carried by optical path 232 in the backward direction to the second distal end port of 2 x 2 device 235_1. As they backward propagate, 2 x 2 device 235_1 multiplexes $\lambda 2B$ and λBB into a fourth subset of optical signals that is output on the first proximal end port of 2 x 2 device 225_1 and carried by optical path 217 in the backward direction to the second distal end port of 2 x 2 device 210_2 in the 1 x 2 optical device 202_1.

[0041]   At 1 x 2 device 202_1, the fourth subset, including $\lambda 2B$ and $\lambda 4B$, received at the second distal end port of 2 x 2 device 210_2 backward propagates through 2 x 2 device 210_2. The fourth subset, including $\lambda 2B$ and $\lambda 4B$, is output on a proximal end port of

device 210_2, and is carried by optical path 212 in the backward direction to the first distal

end port of 2 x 2 device 210_1. Similarly, the third subset, including $\lambda1B$ and $\lambda3B$,

received at the first distal end port of 2 x 2 device 210_3 backward propagates through 2 x

2 device 210_3. The third subset, including $\lambda1B$ and $\lambda3B$, is output on a proximal end port

of device 210_3, and is carried by optical path 214 in the backward direction to the second

distal end port of 2 x 2 device 210_1. The 2 x 2 device 235_1 multiplexes the third and

fourth subsets into an output WDM signal that is output on the second proximal end port

of 2 x 2 device 225_1 on optical path 207 in the backward direction. The output WDM

signal has four channels – $\lambda1B$, $\lambda2B$, $\lambda2B$ and $\lambda4B$ – as shown in FIG 2.

[0042]   Therefore in the backward direction, in accordance with the invention, an

output WDM signal is multiplexed from four optical channels ($\lambda1B$, $\lambda2B$, $\lambda3B$, and $\lambda4B$

that are received a the distal end of the second tier as discrete optical channels on

respective unidirectional optical paths 227, 229, 237, and 239) as the optical channels

backward propagate through the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200.

In the second tier of the cascade (i.e., 1 x 2 devices $202_{2, 3}$), the received optical channels

are multiplexed into separate odd and even optical channel subsets in the respective 1 x 2

devices 202_2 and 202_3. In this illustrative example, each subset contains two optical

channels. Thus, the second tier of the cascade operates in the backward direction to

output, at the proximal end of the second tier, a pair of optical subsets each having double

the channel count of each of the discrete input signals received at the distal end of the

cascade's second tier. The odd and even optical channels subsets are each multiplexed in

the 1 x 2 device 202_1 in the first tier of the cascade to double channel count again and

generate the output WDM signal that is output at the proximal end of the cascade's first

tier on optical path 207. In some applications of the invention, the channel spacing may

thus be approximately halved (i.e., the optical channels are closer together) as the optical subsets backward propagate from the second tier to the first tier of the cascade forming the bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200.

[0043]   Referring now to FIG 3, an illustrative bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300 is depicted that is arranged from seven cascaded 1 x 2 devices, in accordance with the invention. The nomenclature "1 x 8" and "8 x 1" is used to indicate, respectively, the demultiplexing of an input WDM signal into eight discrete signals in the forward direction, and the multiplexing of eight discrete signals into a single output WDM signal in the backward direction.

[0044]   In accordance with the invention, the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300 demultiplexes an input WDM signal received at the proximal end of the cascade into eight discrete optical channels at the distal end. As indicated by the arrow 312, the demultiplexing occurs as the input WDM signal forward propagates through the three tiered cascade forming the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300. In addition, as indicated by the arrow 314, eight discrete channels received at the distal end of the cascade are multiplexed as the channels backward propagate through the three tiered cascade forming the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300. In accordance with the invention, the demultiplexing and multiplexing functions is performed simultaneously using bidirectional optical signal propagation.

[0045]   The 1 x 2 devices, identified by reference numerals 302_{1-7} in FIG 3, are each similar in form and operation to the 1 x 2 device 100 shown in FIG 1 and described in the accompanying text. The cascade forming the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300 is arranged in three tiers where the first tier (designated as m = 1 in FIG 3) comprises a 1 x 2 device 302_1 that is optically coupled to both the 1 x 2 device 302_2

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and the 1 x 2 device 302_3 that are each disposed in the second tier (designated as m = 2 in FIG 3). The 1 x 2 device 302_2 in the second tier of the cascade is optically coupled to both the 1 x 2 device 302_4 and the 1 x 2 device 302_5 that are each disposed in the third tier (designated as m = 3 in FIG 3). The 1 x 2 device 302_3 in the second tier of the cascade is optically coupled to both the 1 x 2 device 302_6 and the 1 x 2 device 302_7 that are each disposed in the third tier.

[0046] The structure of bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300 is similar in form to bidirectional 1 x 4 demultiplexer, 4 x 1 multiplexer 200 shown in FIG 2 and described in the accompanying text. However, in order to provide the additional multiplexing and demultiplexing function for the additional optical channels, a third tier of 1 x 2 devices is added. It may also be recognized that the 1 x 8, 8 x 1 structure may be considered as a bidirectional 1 x 4 demultiplexer, 4 x 1 demultiplexer (formed from 1 x 2 devices 302_1, 302_2 and 302_3) that is coupled to the four 1 x 2 devices 302_4, 302_5, 302_6 and 302_7. Alternatively, the 1 x 8, 8 x 1 structure may be considered as two 1 x 4 demultiplexer, 4 x 1 demultiplexers (the first being forming 1 x 2 devices 302_2, 302_5 and 302_5 and the second being formed from 1 x 2 devices 302_3, 302_6 and 302_7) that are both coupled to the single 1 x 2 device 302_1 and operated in parallel.

[0047] The signal flow through the arrangement shown in FIG 3 is similar to that shown in FIG 2 with the fundamental difference being that eight channels propagate in each direction rather than the four in the previous illustrative example. Accordingly, an input WDM signal having eight optical channels − $\lambda 1F$ to $\lambda 8F$ − is received on the unidirectional optical path 307 at the first proximal end port of 2 x 2 device 315_1 in the 1 x 2 device 302_1 in the first tier of the cascade. An optical isolator 305_1 is disposed along the optical path 307 to prevent feedback to the WDM signal source (not shown in FIG 3).

[0048]   As the input WDM signal forward propagates through 2 x 2 device 315_1, it is demultiplexed into a first subset of four optical channels, $\lambda 1F$, $\lambda 3F$, $\lambda 5F$ and $\lambda 7F$, and a second subset of the other four optical channels, $\lambda 2F$, $\lambda 4F$, $\lambda 6F$ and $\lambda 8F$. The first subset is carried in the forward direction by bidirectional optical path 311 to a proximal end port of 2 x 2 device 315_2. The second subset is carried in the forward direction by bidirectional optical path 313 to a proximal end port of 2 x 2 device 315_3.

[0049]   The first subset of optical channels, including $\lambda 1F$, $\lambda 3F$, $\lambda 5F$ and $\lambda 7F$, forward propagates through 2 x 2 device 315_2, is output on the first distal end port of device 315_2, and is carried by optical path 316 in the forward direction to the first proximal end port of 2 x 2 device 324_1 in the 1 x 2 device 302_2. Similarly, the second subset of optical channels, including $\lambda 2F$, $\lambda 4F$, $\lambda 6F$ and $\lambda 8F$, forward propagates through 2 x 2 device 315_3, is output on the second distal end port of 2 x 2 device 315_3, and is carried by optical path 319 in the forward direction to the second proximal end port of 2 x 2 device 331_1 in 1 x 2 device 302_3. Thus, the even-numbered channels of the input WDM signal are output on optical path 319 and the odd channels are output on optical path 316. In some applications of the invention, the channel spacing of the signals output on paths 319 and 316 may be arranged to be approximately twice the channel spacing of the input WDM signal received on unidirectional optical path 307.

[0050]   As indicated in FIG 3, as the first subset of optical channels, including $\lambda 1F$, $\lambda 3F$, $\lambda 5F$ and $\lambda 7F$, forward propagates through 2 x 2 device 324_1, it is demultiplexed into a third subset of optical channels, including $\lambda 1F$ and $\lambda 5F$, and a fourth subset of optical channels, including $\lambda 3F$ and $\lambda 7F$. The third subset of optical channels, including $\lambda 1F$ and $\lambda 5F$, is carried in the forward direction by bidirectional optical path 323, forward

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propagates through 2 x 2 device 324_2 and is output from the first distal end port to the first proximal end port of 2 x 2 device 342_1 in 1 x 2 device 302_4 via unidirectional optical path 327. The fourth subset of optical channels, including $\lambda 3F$ and $\lambda 7F$, is carried in the forward direction by bidirectional optical path 325, forward propagates through 2 x 2 device 324_3 and is output at the first distal end port to the second proximal end port of 2 x 2 device 351_1 in 1 x 2 device 302_5 via unidirectional optical path 329.

[0051]   The third subset of optical channels, including $\lambda 1F$ and $\lambda 5F$, forward propagates through 2 x 2 device 324_1 where it is demultiplexed so that a single optical channel $\lambda 1F$ is carried in the forward direction by bidirectional optical path 343 to a proximal end port of 2 x 2 device 342_2 and a single optical channel $\lambda 5F$ is carried in the forward direction by bidirectional optical path 344 to a proximal end port of 2 x 2 device 342_3. The optical channel $\lambda 1F$ forward propagates through 2 x 2 device 342_2 and is output on the first distal end port on unidirectional optical path 346. The optical channel $\lambda 5F$ forward propagates through 2 x 2 device 342_3 and is output at the first distal end port on unidirectional optical path 348.

[0052]   The fourth subset of optical channels, including $\lambda 3F$ and $\lambda 7F$, forward propagates through 2 x 2 device 351_1 where it is demultiplexed so that a single optical channel $\lambda 3F$ is carried in the forward direction by bidirectional optical path 352 to a proximal end port of 2 x 2 device 351_2 and a single optical channel $\lambda 7F$ is carried in the forward direction by bidirectional optical path 353 to a proximal end port of 2 x 2 device 351_3. The optical channel $\lambda 3F$ forward propagates through 2 x 2 device 351_2 and is output on the first distal end port on unidirectional optical path 356. The optical channel $\lambda 7F$

forward propagates through 2 x 2 device 351_3 and is output at the first distal end port on unidirectional optical path 358.

[0053] As indicated in FIG 3, as the second subset of optical channels, including $\lambda 2F$, $\lambda 4F$, $\lambda 6F$ and $\lambda 8F$, forward propagates through 2 x 2 device 331_1, it is demultiplexed into a fifth subset of optical channels, including $\lambda 2F$ and $\lambda 6F$, and a sixth subset of optical channels, including $\lambda 4F$ and $\lambda 8F$. The fifth subset of optical channels, including $\lambda 2F$ and $\lambda 6F$, is carried in the forward direction by bidirectional optical path 333 to a proximal end port of 2 x 2 device 331_2, forward propagates through 2 x 2 device 331_2 and is output from the first distal end port to the first proximal end port of 2 x 2 device 364_1 in 1 x 2 device 302_6 via unidirectional optical path 337. The sixth subset of optical channels including $\lambda 4F$ and $\lambda 8F$ is carried in the forward direction by bidirectional optical path 335 to a proximal end port of 2 x 2 device 331_3, forward propagates through 2 x 2 device 331_3 and is output at the second distal end port to the second proximal end port of 2 x 2 device 375_1 via unidirectional optical path 339.

[0054] The fifth subset of optical channels, including $\lambda 2F$ and $\lambda 6F$, forward propagates through 2 x 2 device 364_1 where it is demultiplexed so that a single optical channel $\lambda 2F$ is carried in the forward direction by bidirectional optical path 361 to a proximal end port of 2 x 2 device 364_2 and a single optical channel $\lambda 6F$ is carried in the forward direction by bidirectional optical path 363 to a proximal end port of 2 x 2 device 364_3. The optical channel $\lambda 2F$ forward propagates through 2 x 2 device 364_2 and is output on the first distal end port on unidirectional optical path 366. The optical channel $\lambda 6F$ forward propagates through 2 x 2 device 364_3 and is output at the first distal end port on unidirectional optical path 368.

[0055] The sixth subset of optical channels, including $\lambda 4F$ and $\lambda 8F$, forward propagates through 2 x 2 device 375_1 where it is demultiplexed so that a single optical channel $\lambda 4F$ is carried in the forward direction by bidirectional optical path 372 to a proximal end port of 2 x 2 device 375_2 and a single optical channel $\lambda 8F$ is carried in the forward direction by bidirectional optical path 373 to a proximal end port of 2 x 2 device 375_3. The optical channel $\lambda 4F$ forward propagates through 2 x 2 device 375_2 and is output on the first distal end port on unidirectional optical path 376. The optical channel $\lambda 8F$ forward propagates through 2 x 2 device 375_3 and is output at the first distal end port on unidirectional optical path 378.

[0056] Therefore in the forward direction, in accordance with the invention, as the input WDM signal having eight channels ($\lambda 1F$ through $\lambda 8F$) forward propagates through the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300, it is demultiplexed and the eight optical channels emerge as discrete channels on respective optical paths 346, 348, 356, 358 366, 368, 376 and 378 at the distal end. In the first tier of the cascade (i.e., 1 x 2 device 302_1), the input WDM signal is demultiplexed into separate first and second subsets of optical channels including four odd and four even channels respectively. In some applications, the channel spacing in each of the first and second subsets is approximately twice that of the input WDM signal. Advantageously, the separation of the channels into odd and even subsets with increased channel spacing may be used to deinterleave the input WDM signal.

[0057] The first and second subsets of optical channels are further demultiplexed in respective 1 x 2 devices in the second tier of the cascade. The first subset is demultiplexed into respective third and fourth subsets of optical channels where each has half the channel count of the first subset (i.e., the third and fourth substs each include two

optical channels). The second subset is demultiplexed into respective fifth and sixth subsets of optical channels (each including two optical channels). In some applications of the invention, the channel spacing of the third and fourth subsets is approximately twice that of the first subset. And, the channel spacing of the fifth and sixth subsets may be approximately twice that of the second subset. The third tier of the cascade forming 1 x 8 demultiplexer, 8 x 1 multiplexer 300 operates to demultiplex the third, fourth, fifth and sixth subsets of optical channels to reduce the channel count by half again and generate discrete optical output channels.

[0058]   In the illustrative embodiment shown in FIG 3, eight discrete optical channels – $\lambda 1B$ through $\lambda 8B$ – are received on respective unidirectional optical paths 347, 349, 357, 359, 367, 369, 377 and 379 at respective second distal end ports of 2 x 2 devices 342_2, 342_3, 351_2, 351_3, 364_2, 364_3, 375_2 and 375_3. Optical isolators 305_2, 305_3, 305_4, 305_5 305_6 305_7, 305_8 and 305_9 are disposed along the optical paths, as shown, to prevent feedback to the optical channel sources (not shown in FIG 3). In accordance with the invention, $\lambda 1F$ through $\lambda 8F$ may be substantially equal in wavelength to $\lambda 1B$ through $\lambda 8B$, respectively, and vary only in terms of direction of propagation through the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300. However, such substantial equality is not a requirement imposed by the invention.

[0059]   At 1 x 2 device 302_4 in the third tier of the cascade, $\lambda 5B$ and $\lambda 1B$ are received at respective second distal end ports of 2 x 2 device 342_2 and 342_3. $\lambda 5B$ backward propagates through 2 x 2 device 342_2, is output on a proximal end port of 2 x 2 device 342_2, and is carried by bidirectional optical path 343 in the backward direction to the first distal end port of 2 x 2 device 342_1. Similarly, optical channel $\lambda 1B$ backward propagates through 2 x 2 device 342_3, is output on a proximal end port of 2 x 2 device 342_3, and is

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carried by bidirectional optical path 344 in the backward direction to the second distal end port of 2 x 2 device 342_1. As the optical channels backward propagate, 2 x 2 device 342_1 multiplexes $\lambda 5B$ and $\lambda 1B$ into a seventh subset of optical channels that is output on the second proximal end port of 2 x 2 device 342_1 and carried by unidirectional optical path 340 in the backward direction to the first distal end port of 2 x 2 device 324_3 in the 1 x 2 optical device 302_1.

[0060]   At 1 x 2 device 302_5 in the third tier of the cascade, $\lambda 7B$ and $\lambda 3B$ are received at respective second distal end ports of 2 x 2 device 351_2 and 351_3. $\lambda 7B$ backward propagates through 2 x 2 device 351_2, is output on a proximal end port of device 351_2, and is carried by bidirectional optical path 352 in the backward direction to the first distal end port of 2 x 2 device 351_1. Similarly, optical channel $\lambda 3B$ backward propagates through 2 x 2 device 351_3, is output on a proximal end port of 2 x 2 device 351_3, and is carried by bidirectional optical path 353 in the backward direction to the second distal end port of 2 x 2 device 351_1. As the optical channels backward propagate, 2 x 2 device 351_1 multiplexes $\lambda 7B$ and $\lambda 3B$ into an eighth subset optical channels that is output on the first proximal end port of 2 x 2 device 351_1 and carried by unidirectional optical path 350 in the backward direction to the second distal end port of 2 x 2 device 324_2 in the 1 x 2 optical device 302_2.

[0061]   At 1 x 2 device 302_6 in the third tier of the cascade, $\lambda 6B$ and $\lambda 2B$ are received at respective second distal end ports of 2 x 2 device 364_2 and 364_3. $\lambda 6B$ backward propagates through 2 x 2 device 364_2, is output on a proximal end port of device 364_2, and is carried by bidirectional optical path 361 in the backward direction to the first distal end port of 2 x 2 device 364_1. Similarly, optical channel $\lambda 2B$ backward propagates

through 2 x 2 device 364_3, is output on a proximal end port of 2 x 2 device 364_3, and is carried by bidirectional optical path 363 in the backward direction to the second distal end port of 2 x 2 device 364_1. As the optical channels backward propagate, 2 x 2 device 364_1 multiplexes $\lambda 6B$ and $\lambda 2B$ into a ninth subset of optical channels that is output on the first proximal end port of 2 x 2 device 364_1 and carried by optical path 360 in the backward direction to the first distal end port of 2 x 2 device 331_3 in the 1 x 2 optical device 302_3.

[0062] At 1 x 2 device 302_7 in the third tier of the cascade, $\lambda 8B$ and $\lambda 4B$ are received at respective second distal end ports of 2 x 2 device 375_2 and 375_3. $\lambda 8B$ backward propagates through 2 x 2 device 375_2, is output on a proximal end port of device 375_2, and is carried by bidirectional optical path 372 in the backward direction to the first distal end port of 2 x 2 device 375_1. Similarly, optical channel $\lambda 4B$ backward propagates through 2 x 2 device 375_3, is output on a proximal end port of 2 x 2 device 375_3, and is carried by bidirectional optical path 373 in the backward direction to the second distal end port of 2 x 2 device 375_1. As the optical channels backward propagate, 2 x 2 device 375_1 multiplexes $\lambda 8B$ and $\lambda 4B$ into a tenth subset of optical channels that is output on the first proximal end port of 2 x 2 device 375_1 and carried by optical path 370 in the backward direction to the second distal end port of 2 x 2 device 331_2 in the 1 x 2 optical device 302_3.

[0063] At 1 x 2 device 302_2 in the second tier of the cascade, the seventh and eighth subsets of optical channels are received at respective second distal end ports of 2 x 2 device 324_3 and 324_2. The seventh subset of optical channels, including $\lambda 5B$ and $\lambda 1B$, backward propagates through 2 x 2 device 324_3, is output on a proximal end port of 2 x 2 device 324_3, and is carried by bidirectional optical path 325 in the backward direction to the second distal end port of 2 x 2 device 324_1. Similarly, The eighth subset of optical

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channels, including $\lambda 7B$ and $\lambda 3B$, backward propagates through 2 x 2 device 324_2, is output on a proximal end port of device 324_2, and is carried by bidirectional optical path 323 in the backward direction to the first distal end port of 2 x 2 device 324_1. As the seventh and eighth subsets backward propagate, 2 x 2 device 324_1 multiplexes them into a eleventh subset of optical channels, including $\lambda 1B$, $\lambda 3B$, $\lambda 5B$ and $\lambda 7B$, that is output on the first proximal end port of 2 x 2 device 324_1 and carried by unidirectional optical path 317 in the backward direction to the first distal end port of 2 x 2 device 315_3 in the 1 x 2 optical device 302_1.

[0064]   At 1 x 2 device 302_3 in the second tier of the cascade, the ninth and tenth subsets of optical channels are received at respective second distal end ports of 2 x 2 device 331_3 and 331_2. The ninth subset of optical channels, including $\lambda 6B$ and $\lambda 2B$, backward propagates through 2 x 2 device 331_3, is output on a proximal end port of 2 x 2 device 331_3, and is carried by bidirectional optical path 335 in the backward direction to the second distal end port of 2 x 2 device 331_1. Similarly, The ninth subset of optical channels, including $\lambda 8B$ and $\lambda 4B$, backward propagates through 2 x 2 device 331_2, is output on a proximal end port of device 331_2, and is carried by bidirectional optical path 333 in the backward direction to the first distal end port of 2 x 2 device 331_1. As the ninth and tenth subsets backward propagate, 2 x 2 device 331_1 multiplexes them into a twelfth subset of optical channels, including $\lambda 2B$, $\lambda 4B$, $\lambda 6B$ and $\lambda 8B$ that is output on the first proximal end port of 2 x 2 device 331_1 and carried by unidirectional optical path 318 in the backward direction to the second distal end port of 2 x 2 device 315_2 in the 1 x 2 optical device 302_1.

[0065]   At 1 x 2 device 302_1 in the first tier of the cascade, the eleventh subset of optical signals received at the second distal end port of 2 x 2 device 315_3 backward

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propagates through 2 x 2 device 315_3. The eleventh subset is output on a proximal end port of device 315_3, and is carried by bidirectional optical path 313 in the backward direction to the second distal end port of 2 x 2 device 315_1. Similarly, the twelfth subset of optical signals received at the first distal end port of 2 x 2 device 315_2 backward propagates through 2 x 2 device 315_2. The twelfth subset is output on a proximal end port of device 315_2, and is carried by bidirectional optical path 311 in the backward direction to the first distal end port of 2 x 2 device 315_1. The 2 x 2 device 315_1 multiplexes the eleventh and twelfth subsets of optical signals into an output WDM signal that is output on the second proximal end port of 2 x 2 device 315_1 on optical path 309 in the backward direction. The output WDM signal has eight channels – $\lambda 1B$ through $\lambda 8B$ – as shown in FIG 3.

[0066]   Therefore in the backward direction, in accordance with the invention, an output WDM signal is multiplexed from eight optical channels ($\lambda 1B$ through $\lambda 8B$ that are received at the distal end of the third tier as discrete optical channels on respective unidirectional optical paths 347, 349, 357, 359, 367, 369, 377 and 379) as the optical channels backward propagate through the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300. In the third tier of the cascade (i.e., 1 x 2 devices $302_{4,5,6\,7}$) the received optical channels are multiplexed into two odd channel subsets and two even channel subsets in the respective 1 x 2 devices in the third tier. In this illustrative example, each subset contains two optical channels. Thus, the third tier of the cascade operates to output, at the proximal end of the third tier, four subsets of optical channels each having double the channel count of the discrete input signals received at the third tier's distal end. In the second tier of the cascade (i.e., 1 x 2 devices $302_{2,\,3}$), the received subsets of optical channels are multiplexed into one odd channel and one even channel subset in the

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respective 1 x 2 devices 302_2 and 302_3. In this illustrative example, each subset generated by the second tier contains four optical channels. Thus, the second tier of the cascade operates to output, at the proximal end of the second tier, a pair of optical subsets each having double the channel count of the input subsets received at the distal end of the cascade's second tier. The odd and even optical channels subsets are each multiplexed in the 1 x 2 device 302_1 in the first tier of the cascade to double channel count again and generate the output WDM signal that is output at the proximal end of the cascade's first tier on optical path 309. In some applications of the invention, the channel spacing may thus be halved as the optical subsets backward propagate from the third tier to the second tier to the first tier of the cascade forming the bidirectional 1 x 8 demultiplexer, 8 x 1 multiplexer 300.

[0067] It will be appreciated that the inventive arrangement may be generalized for applicability to any desired optical channel count. That is, a bidirectional 1 x N demultiplexer, N x 1 multiplexer (where N is the optical channel count) may be implemented, in accordance with the invention, by a cascade of (N-1) 1 x 2 devices having m tiers where 2^m = N. The 1 x 2 devices may each be similar to that shown in FIG 1 and described in the accompanying text.

[0068] Each successive tier includes twice as many 1 x 2 devices as in the preceding tier. That is, the first tier includes one 1 x 2 device, the second tier includes two 1 x 2 devices and the mth tier includes $2^{(m-1)}$ 1 x 2 devices. Therefore, for example, to create an N = 16 bidirectional multiplexer, demultiplexer, 15 1 x 2 devices are used in a four-tiered configuration. The first tier includes one 1 x 2 device, the second tier includes two 1 x 2 devices, the third tier includes four 1 x 2 devices, and the fourth tier includes eight 1 x 2

devices. Likewise, an N = 32 bidirectional multiplexer, demultiplexer would include 31 1 x 2 devices arranged in a five-tiered cascade.

[0069]   Each 1 x 2 device in a tier is optically coupled to two 1 x 2 devices in the successive tier. In the forward direction, an input optical signal received at the proximal end of each 1 x 2 device is multiplexed into two separate output subsets of optical signals at the distal end of the 1 x 2 device. One of the output subsets becomes an input signal to one of the coupled 1 x 2 devices in the successive tier, and the other output subset becomes an input signal to the other coupled 1 x 2 device in the successive tier. Thus, in the forward direction, at each mth tier of the cascade, $2^{(m-1)}$ subsets of optical channels are received at the proximal end of the tier, and 2^m subsets of optical channels are output at the distal end of the tier. In applications of the invention, as the optical signals propagates from tier to tier in the forward direction the channel spacing in each output subset approximately doubles until the last tier at the distal end of the cascade is reached where N optical subsets are output where each subset includes a single optical channel.

[0070]   In the backward direction, two separate input subsets of optical signals are received at the distal end of each 1 x 2 device in each given tier of the cascade. Each 1 x 2 device multiplexes the two input subsets into a single output subset. The output subset becomes an input subset to the first one of the distal end ports of a 1 x 2 device in a preceding tier. A second 1 x 2 device in the given tier provides the input subset to the second distal end port of the 1 x 2 device in the preceding tier. Thus, in the backward direction, at each mth tier of the cascade, 2^m subsets of optical channels are received at the distal end of the tier, and $2^{(m-1)}$ subsets of multiplexed optical channels are output at the proximal end of the tier. In applications of the invention, as the signal propagates from tier to tier in the backward direction, the channel spacing in each output subset is

approximately halved until the first tier at the proximal end of the cascade is reached where a single output WDM signal is output from the bidirectional 1 x N demultiplexer, N x 1 multiplexer.

[0071]   Other embodiments of the invention may be implemented in accordance with the claims that follow.